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Investigate The Benefits Of Requiring 95% Relative Compaction In The Top 30 Inches Of The Roadway Section

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16. ABSTRACT
In pursuit of efficient, economic construction of the structural section of pavements, a preliminary investigation reviews the merits of a research project to develop a rational method for selecting compaction requirements. Both the literature search and the preliminary test results indicate some responsiveness of strength to density but the consistency obtained does not indicate that a quantitative compaction requirement is feasible. None of the present design formulas as reviewed adequately provide a means for systematically adjusting the thickness of the upper layers requiring greater density.

As measured by the California R-value test, silty soils yield the greatest improvement in strength due to increased density. Other soils show little change in strength as a result of a density change and all soils exhibit erratic results.

Preliminary tests comparing deflection basin measurements to density and compaction indicate that moisture content influences the strength measurement considerably. The recommendations drawn from this report are to accept a flexible special provision as outlined in the appendix and not attempt to establish a rational method for determining compaction requirements for the upper layers of the roadbed.

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STATE OF CALIFORNIA—TRANSPORTATION AGENCY

RONALD REAGAN, *Governor*

DEPARTMENT OF PUBLIC WORKS

DIVISION OF HIGHWAYS

MATERIALS AND RESEARCH DEPARTMENT

5900 FOLSOM BLVD., SACRAMENTO 95819

July, 1969

Phase I
M&R No. 633390
D-5-23

Mr. J. A. Legarra
State Highway Engineer

Dear Sir:

Submitted herewith is a research report titled:

INVESTIGATE THE BENEFITS OF REQUIRING
95% RELATIVE COMPACTION IN THE TOP
30 INCHES OF THE ROADWAY SECTION

Phase I

ERNEST ZUBE
Principal Investigator

D. O. TUELLER
Co-Investigator

Very truly yours,

JOHN L. BEATON
Materials and Research Engineer

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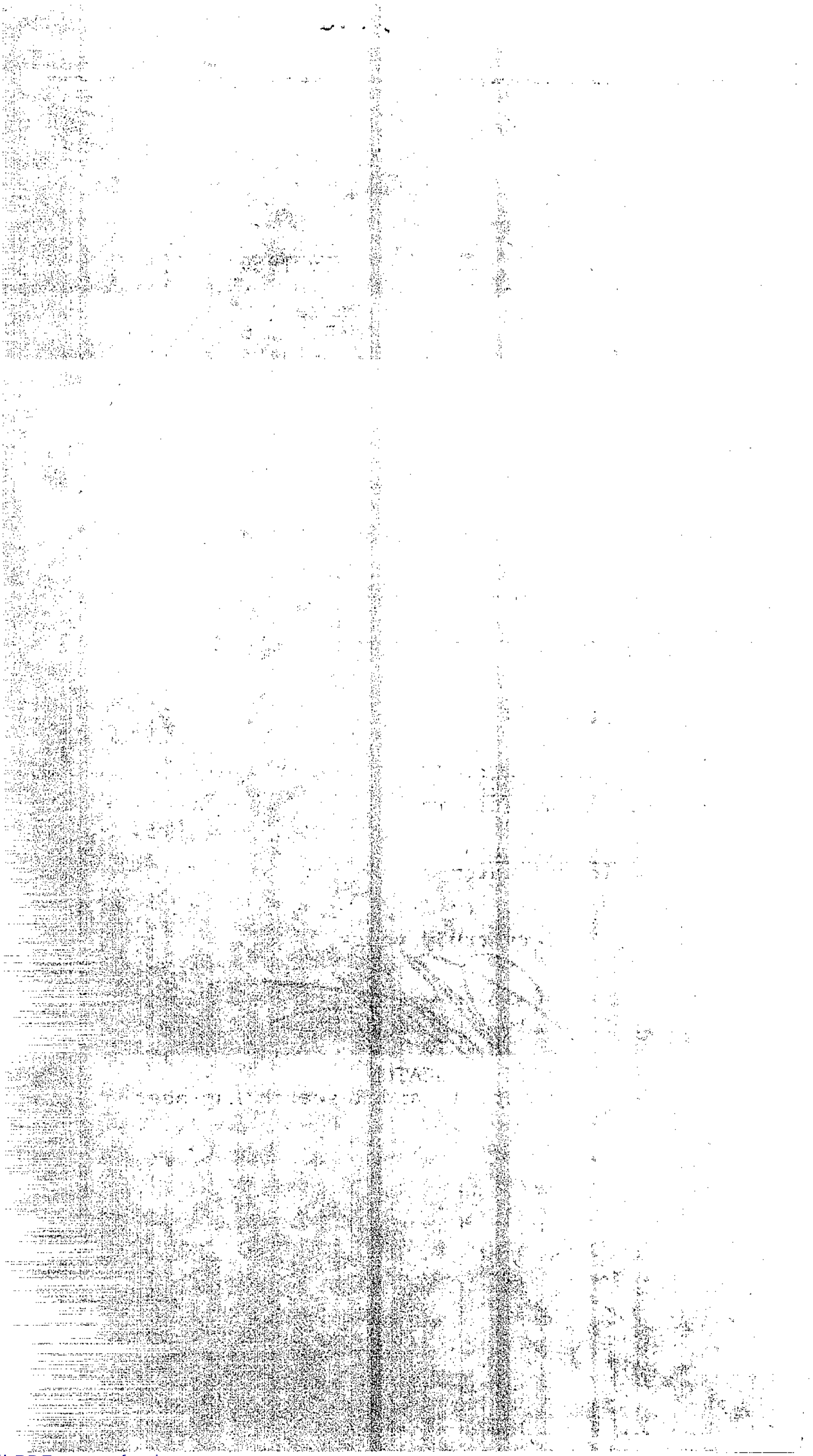

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REFERENCE: Zube, E. and Tueller, D. O., "Investigate the Benefits of Requiring 95% Relative Compaction in the Top 30 Inches of the Roadway Section", State of California, Department of Public Works, Division of Highways, Materials and Research Department, Research Report 633390, July 1969.

ABSTRACT: In pursuit of efficient, economic construction of the structural section of pavements, a preliminary investigation reviews the merits of a research project to develop a rational method for selecting compaction requirements. Both the literature search and the preliminary test results indicate some responsiveness of strength to density but the consistency obtained does not indicate that a quantitative compaction requirement is feasible. None of the present design formulas as reviewed adequately provide a means for systematically adjusting the thickness of the upper layers requiring greater density.

As measured by the California R-value test, silty soils yield the greatest improvement in strength due to increased density. Other soils show little change in strength as a result of a density change and all soils exhibit erratic results.

Preliminary tests comparing deflection basin measurements to density and compaction indicate that moisture content influences the strength measurement considerably. The recommendations drawn from this report are to accept a flexible special provision as outlined in the appendix and not attempt to establish a rational method for determining compaction requirements for the upper layers of the roadbed.

KEY WORDS: Soil compaction, soils, density, requirements, deflection, measurements, moisture content.

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[illegible] compaction requires [illegible]
[illegible] roadbed. [illegible]

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ACKNOWLEDGMENTS

This work was done in cooperation with the U. S. Department of Transportation, Federal Highway Administration, Bureau of Public Roads (Federal Program No. D-5-23). The opinions, findings, and conclusions expressed in this publication are those of the authors and not necessarily those of the Bureau of Public Roads.

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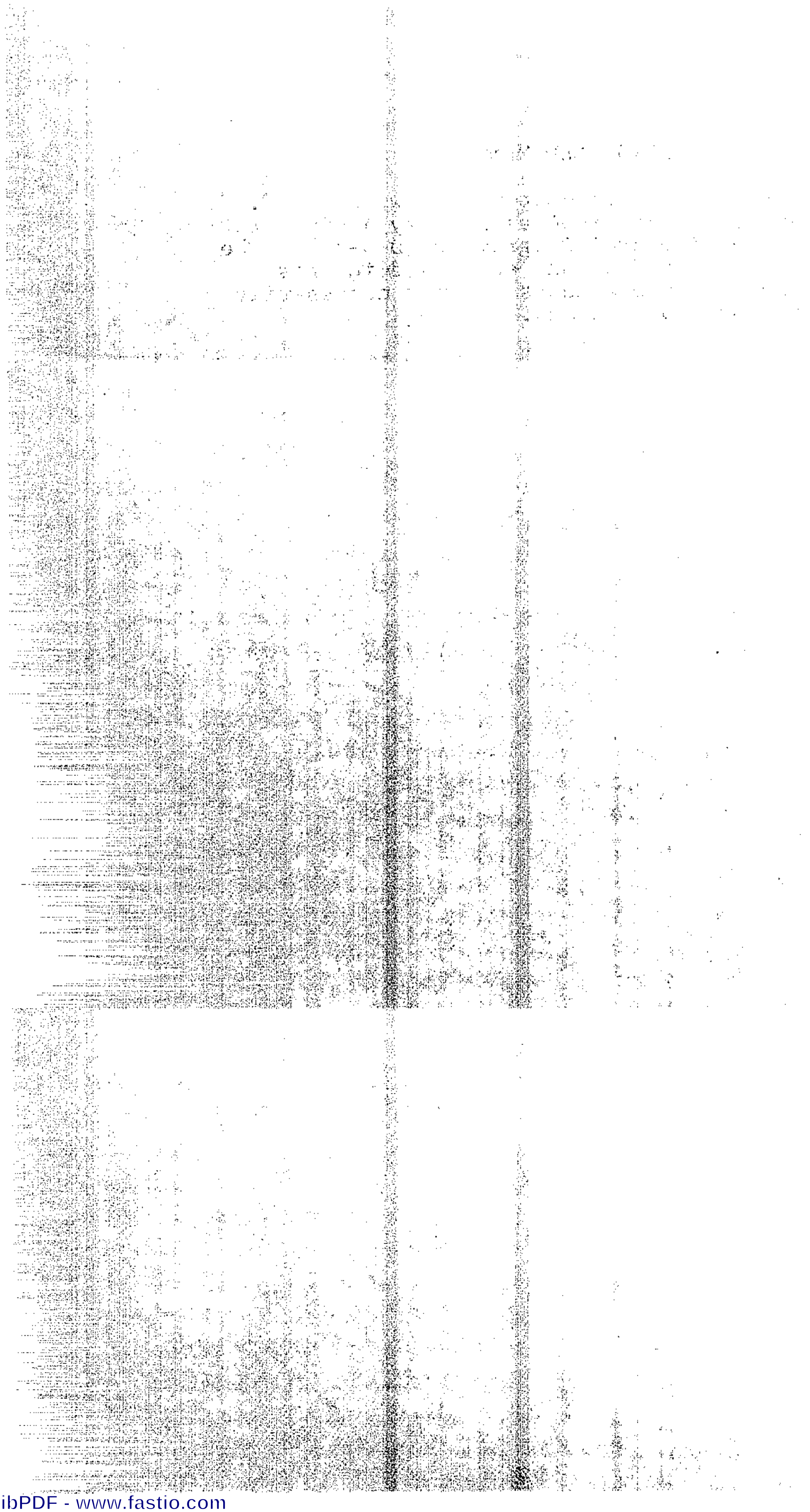

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INTRODUCTION

Compaction is the fundamental process by which the engineering properties of soils or earth materials are improved. The general statement can be made that as the density of a soil is increased there is an increase in the strength of the soil and in the resistance of the soil to deformation or compression.

In normal highway construction practice the densities of the upper layers of embankments and of the materials in the structural section are increased over the density required at greater depths. The Standard Specifications of the California Division of Highways require 95% relative compaction for material within 2.5 feet of the finished surface while embankments below this horizon need only be compacted to 90% relative compaction. Original ground between 2.5 and 3.0 feet below finished surface is to be compacted to a density of 90% relative compaction.

Highway construction costs are increased when greater densities are required. It is the objective of this project to evaluate the benefits from requiring higher relative compaction in the upper layers of the roadbed.

This project was approved for Federal participation for $2,000 to cover Phase I during the 1966-67 fiscal year. No work was done on the project due to the shortage of qualified personnel and the project was delayed.

CONCLUSIONS

Phase I included a search of literature to determine the extent of work done by other researchers. A spot check of specifications from other states and agencies indicates that requiring greater density in upper layers of the roadbed is a common practice. Little research work has been reported that can be directly related to this requirement or that aids in establishing economic limit criteria for establishing levels of varying density. It is not possible at this time to determine the depth of basement soil that requires greater density, nor to relate these factors to the traffic volume of the roadway. Subjective evaluation of the conditions existing at a site provide the best available basis for establishing the thickness limits for compaction requirements.

A study of existing test data reveals a general relationship between density and strength as determined by triaxial shear test, especially if the moisture content is below saturation. Exact relationships cannot be determined due to the difficulty in isolating the effects of the many variables of the soil. Silts are more responsive to the density strength relationship than are clays or sands and gravels.

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A study of 100 R-value tests indicates that for silt soils a slight change in density is reflected by a large change in indicated R-value. This relationship is not so well established for clays, sands, or gravels.

A comparison of deflections measured by the Lane-Wells Dynaflect and densities measured with a backscatter nuclear density gage was made for a sandy silty clay at a single location. This comparison shows a reduction of deflection of subgrade when the relative compaction increases. The scanty data developed from our limited testing program precludes any precise definition of this relationship.

RECOMMENDATIONS

It is recommended that this project be terminated with this report of Phase I. If new pavement design procedures and techniques are developed at a future time, it may be advisable to then explore this subject in greater detail with the hope that a rational design method using appropriate values for the properties of the soils can be developed.

The Construction Department initiated a request to modify the specifications concerning compaction and the current policy of the California Division of Highways is to include in the Special Provisions for each project, clauses to cover the following changes:

Eliminate the requirement for mandatory excavation to the 2.5 foot horizon and allow compaction of the material in place. If the contractor elects to remove the material in order to expedite compaction, the Engineer may order compaction of the layer between 2.5 and 3.0 feet below the finish surface. Such ordered compaction work will be paid for as extra work. Modify the thickness of the layer for which 95% relative compaction is required to the layer that extends to 0.5 foot below the subgrade. This modification will be automatic for structural sections that are thicker than 2 feet and will be permitted by special provision for thin structural sections. The complete Special Provisions and the Circular Letter with an explanatory sketch is included with this report.

The modifications are warranted and it is recommended that they be used as a standard procedure.

REVIEW OF LITERATURE

Smith, T. W. "et al", "Strength Characteristics of Compacted Soils", Research Report No. M&R 226118-1, October, 1965, State of California, Transportation Agency, Department of Public Works, Division of Highways, Materials and Research Department, Sacramento, California.

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This research report provides a comparison of strength characteristics of soils at varying densities. The area covered is somewhat limited but the general relationship of increased strength with increased density is established.

Yoder, E. J. "Subgrades", Principles of Pavement Design, John Wiley, New York, 1959, pp. 224-254.

This text makes repeated reference to the strength-density-moisture relationship and in Chapter 9, Subgrades, the author discusses how pavement design is affected by compaction. He also summarizes the prevailing compaction requirements throughout the United States on a map chart.

Wahls, H. E., Fisher, C. P. and Langfelder, L. J., "The Compaction of Soil and Rock Materials for Highway Purposes", Bureau of Public Roads CPR-11-0954 NCS ERD-197-25, August 1966, Department of Civil Engineering, North Carolina State University of Raleigh.

This report covers the subject of compaction in great detail and tabulates the current practice of the various states. It includes over 60 pages of bibliography containing nearly 400 references.

SPECIFICATIONS FROM OTHER STATES AND AGENCIES

The report by Wahls, Fisher, and Langfelder listed above gives a very complete tabulation of the compaction requirements of the various states. In addition to studying this tabulation a random check of State specifications was made. The specifications of Oregon, Georgia, Kansas, and Texas were selected and studied and without exception these four states require greater density in the top layers of the roadbed over that required at greater depth. The Federal Aviation Agency specifies that subgrades and base courses for airport runways, taxiways and parking aprons be compacted to 95% relative compaction, which is greater density than that required for the embankments.

The foregoing is indicative of the common practice to require increased compaction in the layers immediately underlying the subgrade and in the layers of the structural section.

TRIAXIAL SHEAR STRENGTH VS. DENSITY

The research report "Strength Characteristics of Compacted Soils" shows that in a general way the strength of a soil as measured by the triaxial shear test is related to the density. However, the data contained in this report is rather limited and specific numerical relationships cannot be given. There are individual samples where this relationship is reversed.

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A plot of unconfined compressive strength vs. varying moisture contents for a sandy-clay soil is also shown in this report. The plot indicates that the strength of this soil is very dependent upon the moisture content. This parameter may be a better indicator of strength than is density for the soil type involved.

It is doubtful that further investigation of laboratory strengths of soils compared to density will add greatly to our understanding of the benefits derived by requiring increased compaction in the upper layers of the roadbed.

It is general knowledge that certain soils in their natural undisturbed state possess greater strength at densities below 90% relative compaction than the same soil will possess at 90+% relative compaction if it has been heavily worked to achieve the greater density. We can eliminate from this group material found below the water table, soil that is removed as unsuitable material because of high percentages of organic material or moisture, and low density fine grained soils. It then appears that in the future some testing should be undertaken to define the soils and the conditions where it would be unwise to disturb the in place condition by trying to increase density by heavy rolling. Present knowledge indicates that these are the silty soils especially when they are near saturation. When these soils are encountered near the subgrade horizon special consideration of the specific problem should be given. Relaxation of the density requirement may be warranted and should be allowed after careful evaluation of all the factors involved.

R-VALUE VS. DENSITY

A comparison of the densities of the soil specimens used in the R-value test with the maximum densities for the same samples of soil as determined by Test Method No. Calif. 216 "Method of Test for Relative Compaction of Untreated and Treated Soils and Aggregates" shows that most soils at equilibrium moisture content have R-value densities between 90% and 100% of the maximum densities obtained in the impact compaction mold.

The R-value for a soil is determined at equilibrium moisture content. This point is where moisture is exuded when the soil is subjected to a 300 psi compressive force after the specimen has been compacted by a standard mechanical procedure. To determine this point a series of test specimens that have been prepared with varying moisture contents are tested. The test data are plotted with R-value vs. exudation pressure. The R-value corresponding to 300 psi exudation pressure is picked from the plot. The density is also determined for each test specimen. Copies of test reports provide the data for comparing density and R-value for many soil types. Using the point just above and the point just below the 300 psi exudation pressure line for each sample makes the comparisons fall into the proper range of density to help evaluate the objective of this project.

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A study was made of 100 R-value tests representing a variety of soils from throughout the State. The specimens that plotted just above and just below the 300 psi exudation pressure line were examined for each of the 100 samples. The density and the corresponding R-value for each specimen are plotted in Figure 1. The two points for each soil sample are connected by lines. The soil types are shown by appropriate symbols. A look at this figure makes one aware that silts yield the greatest improvement in R-value due to increased density.

Figure 2 shows a plot of the same two specimens for each of the 100 samples used in Figure 1 with the changes in R-value between the two specimens plotted as ordinates and the changes in densities in pounds per cubic foot plotted as abscissas. This plot illustrates again that a minor change in the density of a silt soil results in much improvement in strength as measured in the R-value test. Clay soils show much less improvement and sands and gravels are very erratic. Approximately 20% of the samples exhibited a reversal of the normal pattern of increase of R-value with increased density. This reversal occurred most often in the sands and gravels.

DEFLECTION VS. DENSITY

Early in Phase I of this study it was realized that existing test data were not going to provide the specific answers to the problem. A program of limited field testing was used to obtain data on a single soil type (sandy, silty, clay) at one location to provide a comparison of deflections obtained with a dynaflect unit with in-place density. Approximately 170 individual deflection measurements representing 18 test locations of varying density were made.

The data obtained in this field study was compared in several ways. Two plots are included:

Figure 3 shows the relative compaction of the test locations plotted as abscissas and the slope of the deflection basin at each location plotted as ordinates. Since the geophones are one foot apart the slope value in percent is the difference between the readings of the two geophones divided by 12 multiplied by 100. This graph shows a general trend of decrease in maximum slope of deflection basin as the relative compaction increases. Attempts to isolate relationships of locations with the same percentages of moisture were not meaningful.

Figure 4 shows the relative compaction of the various test sites plotted as abscissas and the maximum deflections as determined by the 1st geophone for the point where the in-place density was determined plotted as ordinates. Again the trend established shows decrease of deflection with increase of compaction.

At three points on Ygnacio Valley Road in Contra Costa County deflections were measured with the dynaflect and determinations of moisture and density of the in-place soil were obtained.

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The soils at these three points are classified as A-6 by the AASHO 1955 classification standards. Table 1 shows that one sample is different from the other two due to grading differences. Of the two similar samples the one from Sta. 172+50 shows only 1/3 as much deflection as the sample from Sta. 163+50 Rt. even though relative compactions vary by only 1% and in this instance the higher relative compaction is associated with the greater deflection. It appears that for these samples moisture content, which varies by 5% of the dry weight, is more important than density in determining strength measured by deflection.

TABLE 1 Samples from Ygnacio Valley Road.

Station	163+50 Rt	163+50 Lt	172+50 Lt
Sieve Analysis		% Passing	
No. 8	94	83	96
No. 16	90	73	91
No. 30	89	65	90
No. 50	86	59	75
No. 200	70	48	72
5 Micron	28	14	31
1 Micron	19	8	21
In-Place Density			
Dry wt. lbs/ft^3	109.6	117.2	110.6
In-Place Moisture %	13.8	8.6	8.4
Max Density Dry Wt			
lbs/ft^3	118.3	122.0	120.6
Opt.Moisture %	12.6	10.2	10.5
Relative Compaction %	93	96	92
Dynaflect Deflection			
10^{-3} inches	4.5	2.5	1.6

The construction of the service road to the new Materials and Research Annex Building provided an opportunity to make one more comparison of deflection and density. The deflection as measured by the dynaflect and the in-place density as determined with a nuclear gage showed a reversal of the expected relationship. The greater deflection was associated with the greater density. Accurate moisture determinations were not obtained and it is felt that extreme variations of this parameter caused the unpredicted results.

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Although it is recognized that great difficulties can be expected when attempting to relate only two variables of soils as in these brief field studies, further work should be undertaken to find relationships between density and deflection through a range of subgrade soils. Some attempt to eliminate the affect of moisture variation should be made.

CURRENT PRACTICE

It has been the practice in California to reduce the compaction requirements for the top layers of the roadbed below those specified in the Standard Specifications whenever conditions for individual projects have warranted such a reduction.

Where a lightly traveled roadway requires only a thin structural section and where grading is minimal, it is sometimes advantageous to reduce the thickness of the layer in which higher compaction is required to less than 30 inches.

Certain natural soils are extremely difficult to compact to 95% relative compaction. In these cases some lesser degree of compaction may be specified. Sometimes adjustments in the thickness of other structural section layers is made to compensate for such a reduction.

Widening projects generally require dig-out only for the depth of the new structural section in order to reduce the depth of the trench adjacent to traffic.

Decisions to relax requirements for compaction in the top 30 inches should continue to be made on an individual project basis. In the past such modification has been accomplished by including appropriate clauses in the Special Provisions. The changes proposed by the Construction Department and now adopted as a Standard Special Provision will facilitate this procedure. They are attached in Appendix 1.

Selection of the specification requirements for density of the top layers of the roadbed must be based on experience and past performance. This idea is summed up by these two statements lifted from the report by Wahls, Fisher and Langfelder:

"---it is not possible to designate quantitative compaction requirements that will be applicable to all conditions. However, it may be noted that presently specified density levels appear to be reasonably satisfactory."

---"At present, quantitative variations in percent compaction requirements as functions of soil type and/or maximum dry density cannot be justified on a rational basis."

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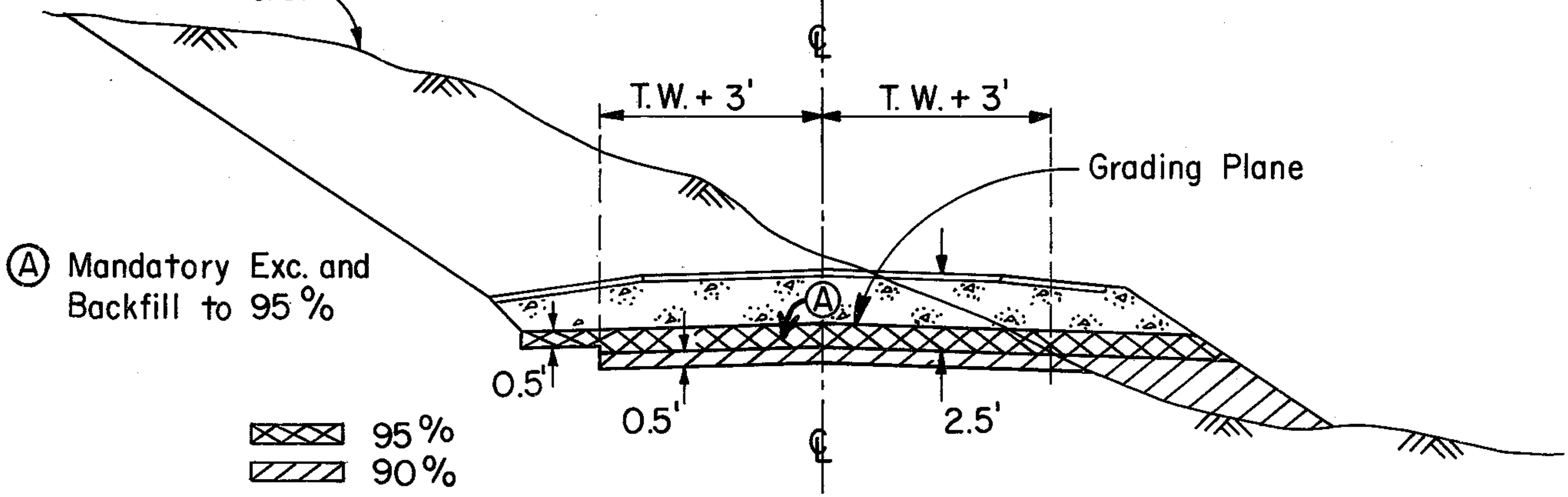
PRESENT 19-5 & 19-6.02



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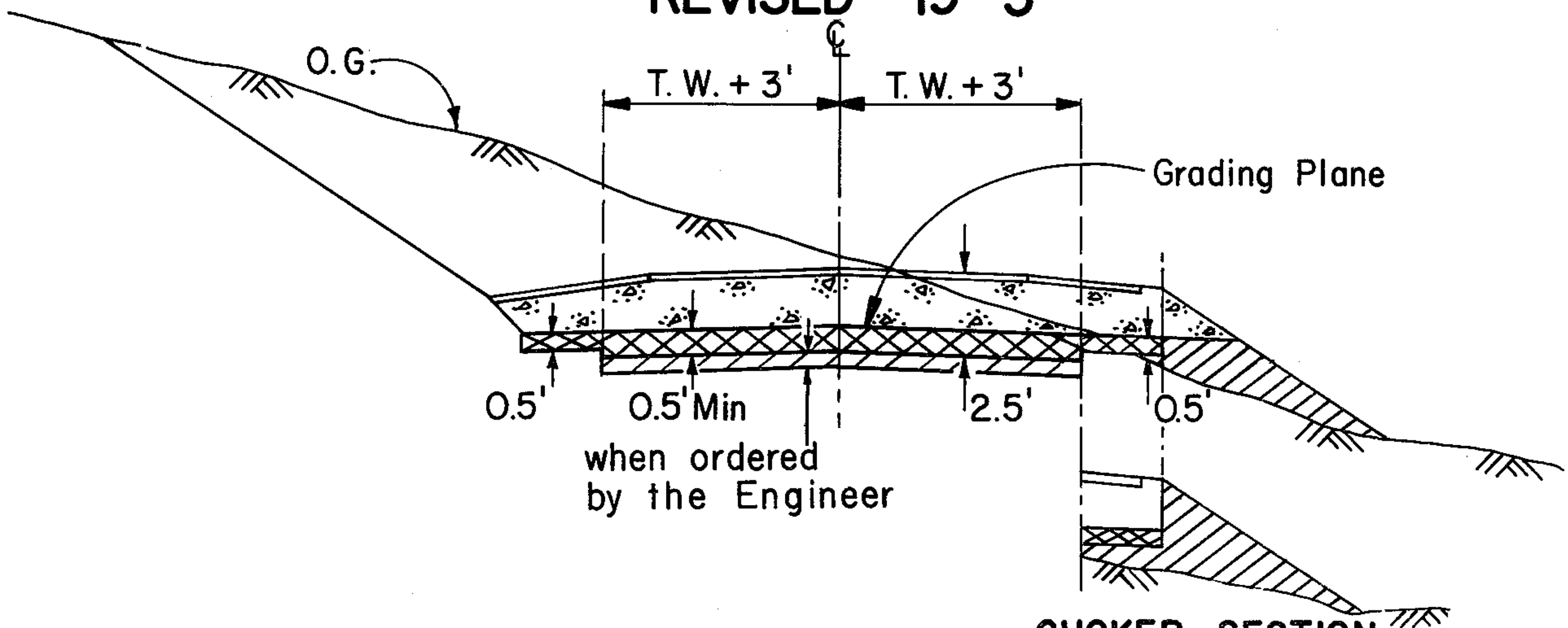

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STATE OF CALIFORNIA DEPARTMENT OF PUBLIC WORKS DIVISION OF HIGHWAYS **CIRCULAR LETTER**	FILE CLASSIFICATION Operations - Construction No. 89	NO. 69-16
TO: **ALL DISTRICTS AND HEADQUARTERS**	DATE ISSUED: January 23, 1969	DATE EXPIRED: January 23, 1970
SUBJECT: Revised Specification* for Earthwork* Compaction*		
REFERENCE: Sections 19-5 and 19-6.02 of Standard Specifications		

Attached is a revised specification for earthwork compaction. This specification supersedes Section 19-5, "Basement Material", of the Standard Specifications, and the portion of Section 19-6 which is concerned with embankment compaction. A drawing is also attached for illustration of the new specification.

The revised specification consolidates similar earthwork compaction requirements into one section and should eliminate the confusion between "compact original ground" and "preparation of subgrade" which has sometimes existed among contractors and engineers.

In addition to changes in wording and format, there are changes in compaction requirements. Mandatory excavation of basement material that is less than 95% relative compaction is no longer required. Instead, the end result of 95% compaction is specified.

The lateral limits of 95% compaction in embankment will now extend only to the outside edges of finished shoulders, rather than to the intersection of the grading plane with the side slopes.

Previously, in excavation and between 3 feet outside the traveled way and the edge of shoulder, 95% compaction was required only for a depth of 0.5-foot below the grading plane, while in embankment 95% was required to a depth of 2.5 feet below finished grade. The new specification now makes the embankment requirement consistent with the excavation requirement.

Compaction of the layer of basement material between 2.5 and 3 feet below finished grade to 90% relative compaction is no longer to be performed as a contract item. The specification now provides that when the contractor elects to excavate and replace basement material in order to achieve the specified 95% compaction, prior to replacement the Engineer may order compaction of the remaining in-place material and this work will be paid for as extra work.

This compaction work should normally be done when the layer of material between 2.5 ft. and 3.0 ft. below finished grade has less than 90% relative compaction. This work should continue until 90% has been obtained, except in the rare cases when this compactive effort might lower the supporting capacity of the soil. Since the necessity for and extent of this work will not be known at the time of bidding, payment will be made as extra work.

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The reasoning behind this specification is that, if the contractor can obtain 95% compaction to the required depth fairly easily, without excavating, it is very likely that at least 90% will also be obtained in the layer between 2.5 and 3 feet below finished grade. Conversely, if 95% cannot be obtained without excavating and replacing, it is likely that extra effort will be required to obtain 90% in the lower layer.

J. A. LEGARRA
State Highway Engineer

Attachments

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This special provision will be added to Standard Special Provisions 19.01, 19.02, 19.05, 19.06 and B 19.50.

1-20-69

The provisions in Section 19-5, "Basement Material," and the fourth paragraph in Section 19-6.02, "Compacting," of the Standard Specifications are superseded by the following:

A. DESCRIPTION.--Earthwork compaction consists of obtaining the required relative compaction in all earthwork described in the Standard Specifications or these special provisions, except structure backfill.

The loose thickness of each layer of embankment material before compaction shall not exceed 0.67-foot, except as provided for rocky material in Section 19-6.02, "Compacting," of the Standard Specifications. Each layer shall be compacted in accordance with the requirements hereinafter specified.

B. RELATIVE COMPACTION (95 PERCENT).--Relative compaction of not less than 95 percent shall be obtained for a minimum depth of 0.5-foot below the grading plane for the width between the outer edges of shoulders, whether in excavation or embankment.

In addition, relative compaction of not less than 95 percent shall be obtained for a minimum depth of 2.5 feet below finished grade for the width of the traveled way and auxiliary lanes plus 3.0 feet on each side thereof, whether in excavation or in embankment.

Relative compaction of not less than 95 percent shall be obtained for embankment under bridge and retaining wall footings without pile foundations within the limits established by inclined planes sloping 1 1/2:1 out and down from lines one foot outside the bottom edges of the footing.

C. RELATIVE COMPACTION (90 PERCENT).--Relative compaction of not less than 90 percent shall be obtained in all material in embankment, except as specified herein to be 95 percent.

D. FOUNDATION PREPARATION.--If the Contractor elects to excavate and replace basement material to facilitate compaction, before replacement has begun and when ordered by the Engineer, a layer of material below the excavated material shall be compacted to the depth, width and degree of compaction ordered by the Engineer, and such work will be paid for as extra work as provided in Section 4-1.03D of the Standard Specifications.

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E. PAYMENT.--Payment for earthwork compaction will be considered as included in the various contract items of work requiring compaction of earthwork and no separate payment will be made therefor, except for applying water. Applying water shall conform to the provisions in "Watering" of these special provisions. If the Contractor elects to excavate and replace basement material to facilitate compaction, the cost of such work will be considered as included in the contract items of work involved and except as hereinafter provided, no separate payment will be made. If such basement material is placed in embankment or used in other planned or authorized work, and is replaced with planned excavated material or imported borrow, payment will be made for the quantity of replacement material used at the contract unit price for the type of excavation involved or imported borrow, as the case may be, except that the quantity of overhaul of replacement material from said excavation to be paid for shall not exceed that required for the original planned haul.

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Figure 1

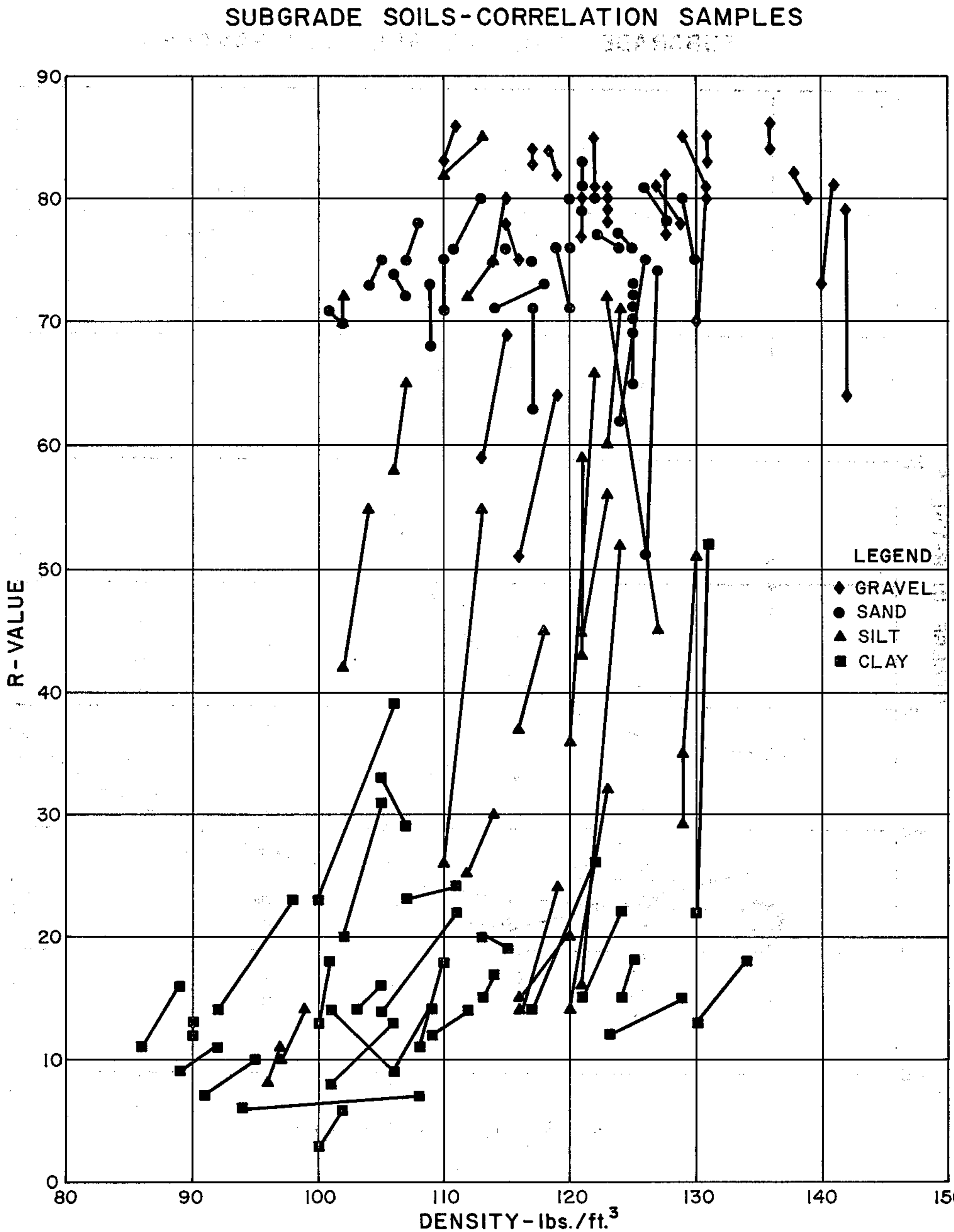

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Figure 2

SUBGRADE SOIL - CORRELATION SAMPLES

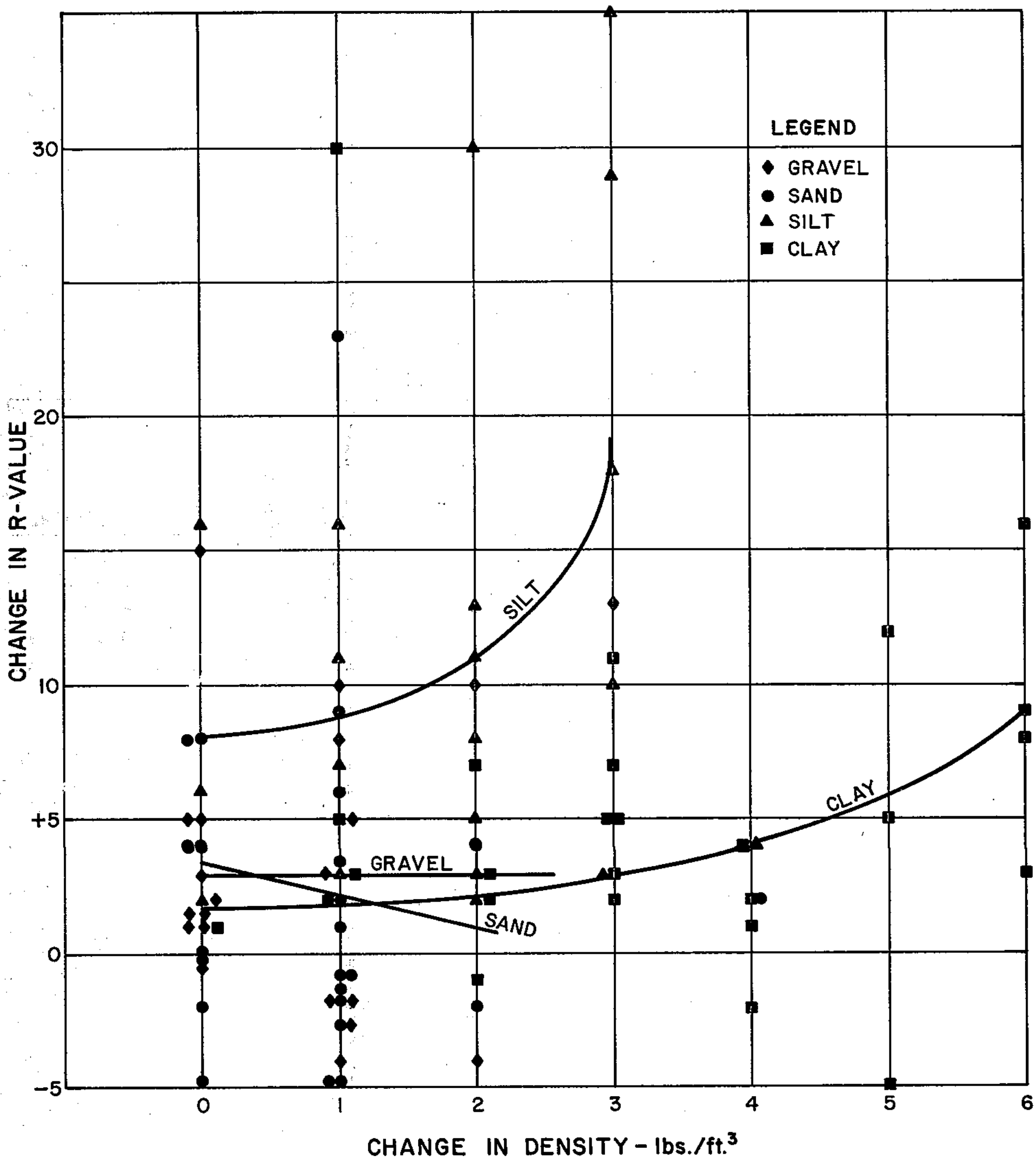

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Figure 3

SLOPE OF DEFLECTED BASIN VS. RELATIVE COMPACTION

Sandy Silty Clay

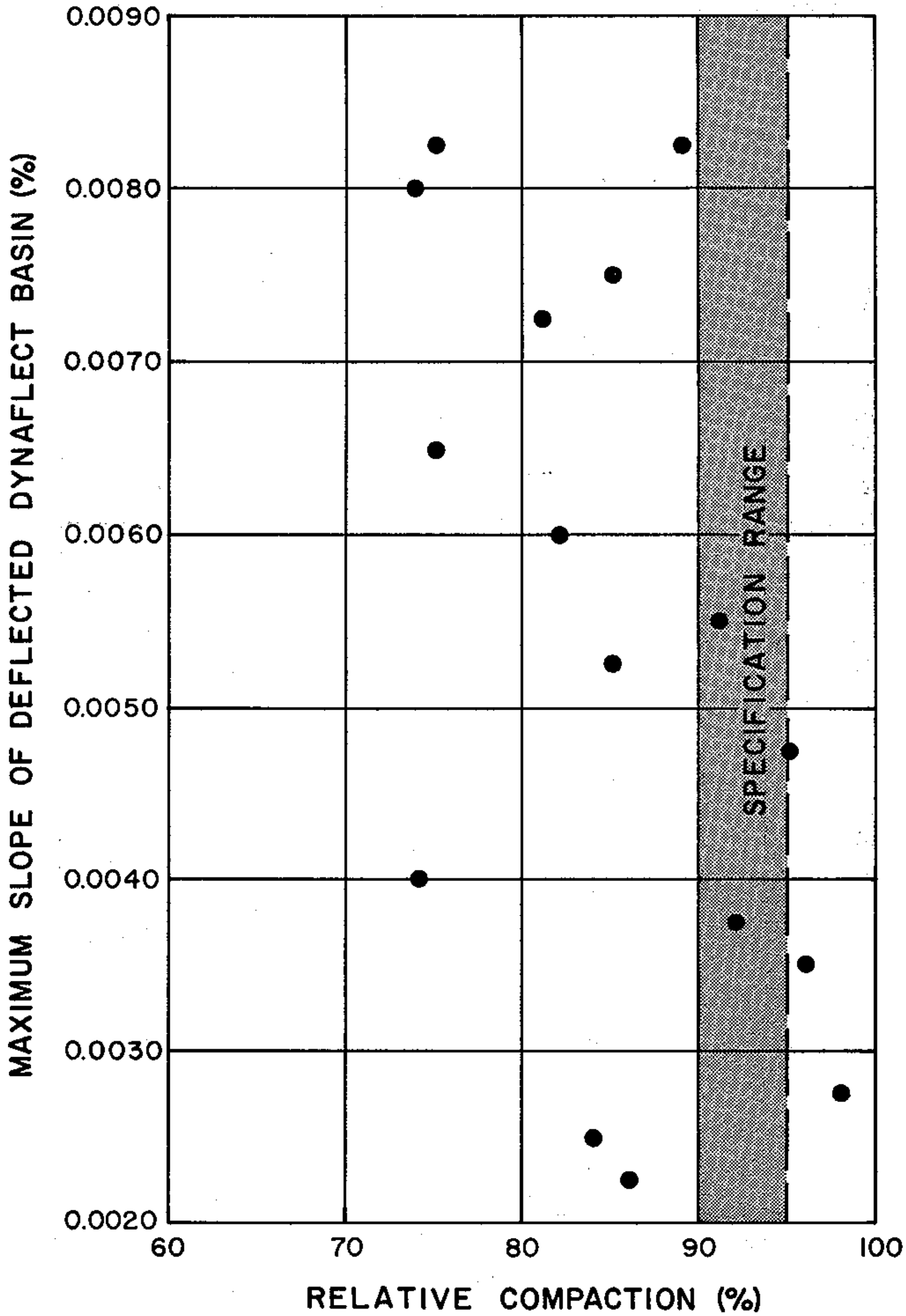

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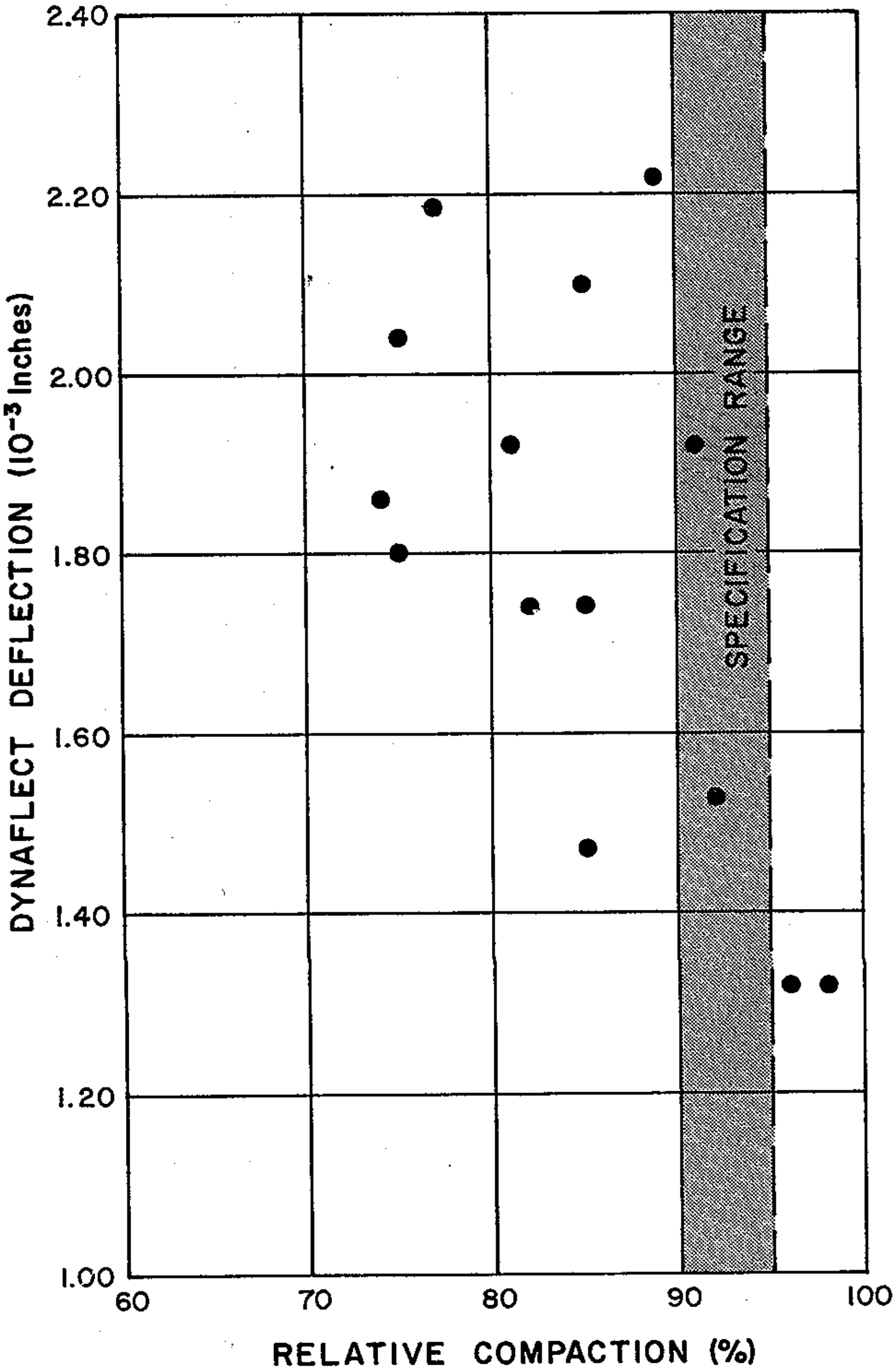
Figure 4

DYNAFLECT DEFLECTION VS. RELATIVE COMPACTION
Sandy Silty Clay



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